A Design Solution to Big Sagebrush Establishment: Seed Production Plots and Facilitation

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Abstract

Big Sage (*Artemisia tridentata* ssp. *wyomingensis*) has proven difficult to re-establish in the Powder River Basin of Wyoming due to drought, plant competition, economics, and other factors. Planting unit design that takes into consideration the natural reproductive strategy of big sage could have a substantial impact on the economics and success of sage establishment. In general, the reproductive strategy of sage is to produce a large amount of short-lived seed with highly variable viability over a long life span. Actual establishment of seedlings results from infrequent stochastic events that create favorable conditions for germination and growth. Thus, the concept of direct-seeding sage as a one-time event is contradictory to the reproductive strategy of sage. In addition, studies have been conducted which demonstrate that large edge-to-area ratios result in increased invasion by species into otherwise stable habitats. A re-interpretation of this concept suggests that species with invasive qualities (i.e. – big sage) and high seed production may benefit from long-linear populations and adjacent disturbed habitats. Bitterroot Restoration Inc. proposes a design solution that emulates the natural strategy of sage reproduction. The proposed design solution would utilize the planting of containerized sage into linear "seed production plots" and adjacent "facilitation beds" which receive an annual seed rain. The proposed solution is supported by both field data from an existing replicated study in Wyoming and case studies of similar projects on high cost reclamation projects. We hypothesize that this long-term view of shrub establishment based upon species reproductive strategy will result in sage stands capable of achieving bond release.

Introduction

Restoration of big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) to mined lands in Wyoming is mandated by both the Wyoming Department of Environmental Quality and the Office of Surface Mining. Current regulations require a post-mining shrub density of 1 shrub per meter^2 on 20% of the affected mining area. This requirement has stimulated substantial research into establishment techniques based upon the use of seed as the main propagule source (Meyer 1994; Schuman et al. 1998). Historically, establishment techniques based upon the use of seed have been largely unsuccessful (Chambers et al.1994; Booth et al. 1999). Although recent advances in seed quality and seeding technology have furthered the successful use of seed in reclamation, they have not produced results that will meet bond release. A second, but less publicized method with substantially higher success is the use of containerized live plant materials. By industry standards this method is generally considered to be economically prohibitive. The purpose of this paper is to

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contrast seeding versus outplanting of containerized materials and to propose a hybrid establishment system which will potentially result in greater success than either of the present methodologies.

Seeding as a Restoration Technique

Seeding of big sagebrush has generally resulted in marginal establishment rates (Meyer 1990; Brown et al. 1991; Chambers et al. 1994; Booth et al. 1999). Booth and others reviewed pre-1985 reclaimed lands seeded with big sagebrush in Wyoming and found that none would meet the 1996 shrub requirement (Booth et al. 1999). Brown et al. (1991) conducted a Nevada study comparing various reclamation techniques which resulted in no establishment of sage seedlings after three years of monitoring . In a Wyoming comparison of seeding rates and live planting, Meikle et al.(1995) also failed to establish sagebrush from seed. Failure of seeding is due to many reasons including improper matching of genetics (Meyer 1990), depauperate mycorrhizal populations (Schuman et al. 1998), variable seed quality (Meyer 1994), plant competition (Cockrell et al. 1995), browse damage (Hoffman and Wambolt 1996), as well as the commonly accepted influence of droughty weather during the time of seedling establishment (several authors). The main reason for seeding failure may not be a misunderstanding of seeding strategies, but rather a lack of understanding of the reproductive biology of sagebrush.

Meyer (1994) and Mozingo (1987) both provide excellent reviews of sagebrush reproductive biology. Big sagebrush is a small-seeded species with seeds typically 1.0 mm X 0.7 mm in size. As with most small seeded species, big sagebrush produces an abundant quantity of seed. It has been estimated that a single shrub with a 1 meter crown will produce 450 flowering branches and at least 350,000 seeds. In a good year, seed production can exceed 1,000,000 on an individual plant. Seed production is subject to annual differences in moisture, frost events, intra-specific competition, and other factors. Xeric upland Wyoming big sagebrush is noted as not setting seed except in wet years. Being self-fertile, individual plants can set seed regardless of the distance to their nearest neighbor. In general, flowering occurs between August and October with subsequent seed dispersal occurring from October through January. Seed dispersal is accomplished via animals and the wind. Sage seed is generally short-lived although this has been questioned by some researchers (Cockrell et al. 1995). A majority of seed planted or produced in a given year is gone from the seed bank by the following spring (Meyer 1994). Seed is generally lost through germination in winter or spring. The fraction of the seed that enters the seed bank is less than 1% (Meyer 1994). Thus, seeding of sage in a given year is likely to fail unless weather conditions and seed viability are conducive to immediate establishment.

Recruitment of sagebrush seedlings is strongly limited by abiotic and biotic factors. Newly emerged seedlings are susceptible to frost damage, drought, and damping off disease. Some factors such as snow cover can effectively increase establishment success. In one study seedling emergence was increased substantially over controls with placement of a snow fence to capture moisture (Meyer 1994). In addition, companion plants have been demonstrated to ameliorate site conditions and allow for greater survival of seedlings and establishment (McArthur et al. 1995). Surviving seedlings begin to flower at about 4 years of age. Big sagebrush in southeastern Idaho on average survives to 4 years of age but commonly exceeds 40 years with some specimens surviving for more than 100 years (West 1988).

Ultimately, planting of big sage via seeding has failed to produce consistent stand establishment. However, these failures are understandable and predictable in light of the natural history of the species.

Outplanting as a Restoration Technique

Outplanting of containerized big sagebrush has generally resulted in high establishment rates although studies and actual monitoring data are few and far between. Fall planted seedlings have resulted in plant survival in excess of 90% over six years of monitoring on one southeastern Montana mine site (P. Martin, personal communication 1999). Survival of late spring planted seedlings on a particularly harsh Wyoming site resulted in 23% survival over five years of monitoring (Meikle 1999). Several variables that are not easily controlled in seeding operations can be controlled under greenhouse production. Plant materials produced for outplanting procedures are grown under greenhouse conditions in conical 10 cubic inch containers that promote deep-rooted seedlings. Growth in such containers bypasses the vulnerable seedling stage which seeded materials must pass prior to becoming drought and frost hardy. Small quantities of appropriate seed sources can yield large quantities of plant materials which allow for the exact matching of site genetics. In addition, vesicular-arbuscular-mycorrhizal inoculants (VAM) are currently available from several companies and can be applied to plant materials prior to or at the time of outplanting thus mediating low nutrient and soil moisture conditions. Furthermore, plants can be placed in appropriate microsites during hand outplanting operations.

Despite high survival rates, outplanting of big sagebrush is not without problems. Outplanting remains a labor intensive and costly enterprise. Although it is long-lived, it is apparent that true restoration of sage will require continual recruitment within a suitable seedbed in order to persist and dominate a site over a period of time. Thus, even though sage may be successfully planted on a site, their long-term existence is not guaranteed unless an appropriate vegetation surrounds stands and allows for continual colonization and recruitment of new individuals. However, shrub densities that could potentially meet bond release within short time periods offset these barriers.

Proposed Design Solution

Our proposed strategy is based both on species biology and design of planting units. This strategy recognizes that seeding efforts are contradictory to the reproductive strategy of big sagebrush and that long-term establishment requires continual recruitment into the existing population. Bitterroot Restoration Inc. proposes a design solution to facilitate the establishment of sagebrush from propagules using a series of “seed production plots” which act as a propagule sources and “facilitation beds” which as propagule acceptors.

The proposed planting unit design would be designed with two components: 1) seed production plots and 2) facilitation beds. The purpose of the seed production plots would be to provide a continuous source of propagules and microbial inoculum for the planting unit. Seed production plots would consist of live-planted containerized sagebrush seedlings that are inoculated with mycorrhizal fungi. Within plots, big sagebrush would be planted in linear strips similar to shelterbelts in the western United States in order to maximize the potential spread of seed rain within the planting unit. Facilitation beds will consist of specially prepared and planted spaces between the seed production plots. The purpose of these beds will be to provide an area conducive to sage establishment for an extended period of time. Facilitation beds will be prepared with a shallow topsoil layer and planted to vegetation that is characteristically susceptible to invasion by big sagebrush. For example, bunch grasses are far less aggressive than sod-forming grasses and will allow open soil microsites that will facilitate sage establishment from wind blown seed provided by the linear sage plantings.

The impacts of seed rain and other dispersal mechanisms have been evaluated in other biomes with generally positive results (Myster and Sarmiento 1998; Urbanska et al. 1998; Toh et al. 1999). Where large areas are to be revegetated, scattered plantings rather than large-scale and intensive plantings may represent an economically attractive option. This approach has been demonstrated successfully in Queensland, Australia through the use of clumped perch trees that act to attract frugiverous birds which subsequently seed tree species into previously forested areas (Toh et al. 1999).

In the western US, several researchers have recommend the planting of small islands of sage surrounded without any grass seeding on relatively flat grounds in order to facilitate establishment (Schuman et al. 1998; Meyer 1994). Dispersion of big sagebrush seed has been quantified with dispersal by wind reaching up to 30 m (Meyer 1994). Recruitment, consequently, tends to be greater on the windward side of the plant due to the prevailing wind direction on seed dispersal. Several authors have witnessed recruitment over time. Brown et al.(1991) conducted an extensive study on a Nevada waste dump site which evaluated several reclamation treatments including topsoil application, mulch application, various seeding rates, and various fertilization rates. Of several species planted by seed, only big sage and black sage failed to appear in test plots during three years of monitoring. During the final year of monitoring, big sagebrush seedlings were noted in depressions adjacent to the study site and were assumed to be the result of seed rain on adjacent native shrublands. Similarly, Meikle et al. established test plots on a northern Nevada site and located volunteer sage seedlings within two years after establishment of a planted bunchgrass community on waste rock. Schuman et al. (1998) and Meyer (1994) noted similar delays in seedling establishment in Wyoming.

The use of companion vegetation which is conducive to invasion by sage has also been recognized by others. Rubber rabbitbrush (*Chrysothamnus nauseousus*) has been noted as compatible with sage establishment (McArthur et al. 1995). Early successional grass species such as squirreltail grass (*Sitanion hystrix*) and saltbush (*Atriplex* sp.) have been noted as compatible as well. Big sagebrush colonized a matrix of dryland bunchgrasses dominated by bluebunch wheatgrass (*pseudorpegneria spicata*), basin wildrye (*Leymus cinerus*), and Sandberg bluegrass (*Poa secunda*) in Nevada (Meikle and Lu 1997). In general, seedling survival is a function of both light availability, plant size and gap size. Big sagebrush seed requires light for germination and plant canopies which allow for greater penetration of light increase the potential for invasion. Subsequently, shelter from adult plants increases plant survival as long as sufficient gap space exists.

Cheatgrass (*Bromus tectorum*) and high fertility agronomic grasses tend to eliminate entirely the recruitment or establishment from seeds. Chambers et al. (1994) states that highly competitive forage species have resulted in limited establishment of native species on reclaimed lands. The result is that 14 years after reclamation on a southeast Idaho study site, big sagebrush had not re-invaded the study plots. This may have been aggravated by addition of legumes such as alfalfa (*Medicago sativa*) and sweet clover (*Melilotus sp.*) which increase soil nitrogen levels. In addition, litter cover on sites excludes the invasion of certain species. This may be particularly relavent to sage invasion onto sites. Chambers et al. (1994) concluded that changes to current reclamation methods will need to be made to facilitate natural successional processes which encourage establishment of native species. Particularly those later successional species which require disturbance and open space for establishment.

Conclusion

Successful sage restoration will require an understanding of the reproductive biology of big sagebrush, a planting strategy which reflects this, and an appropriate understanding of "ecological time." The proposed design approach uses containerized plantings as a source of continuous seed rain into adjacent facilitation beds that contain companion plants with growth characteristics conducive to big sage establishment. Given the large areas areas to be restored, highly designed scattered plantings relying upon containerized plant materials rather than large-scale and intensive plantings may represent an economically attractive option to reclamationists in the western US.

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